Waveguide-to-Microstrip Transition With Integrated Bias-T

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***Abstract*—A novel device, a waveguide-to-microstrip transition with an integrated bias-T, is presented. The substrate-based planar structure comprises a waveguide E-probe, shaped as a radial line. The probe couples the RF field of a full-height waveguide to a microstrip line or directly to an active component, e.g., a transistor or diode in a mixer or direct detector. The radial probe is connected on its wide side to another port via a specially shaped high impedance line that provides RF/DC isolation. This port can then be used to inject DC and/or extract IF signals.**

The design of the presented structure was done using CAD (3-D EM simulation) and an X-band device was produced and fully characterized. The measured performance is in excellent agreement with the simulations; the device has return loss better than −20 dB, insertion loss less or equal to −0.15 dB and isolation for the bias-T line better than −20 dB. RF bandwidth for the transition is 30% of the central frequency.

***Index Terms*—Bias-T, full-height waveguide, waveguide-to-microstrip probe.**

I. Introduction

WAVEGUIDE-BASED active components are mostly produced using thin-film technology and are substrate-based. In order to ease integration of such a device into waveguide, these components are typically integrated with some kind of waveguide probe, providing convenience for installation into a waveguide block and avoiding complexity and stray parameters of a package. In this paper we propose a device, which is a planar structure comprising two functional components. The first is a waveguide-to-microstrip transition consisting of a planar E-probe that transforms the waveguide characteristic impedance, about 400 Ω, into an impedance of about 40–50 Ω, more suitable for active components, and couples it to a microstrip line in a wide frequency range. The second component is a bias-T that allows us to add an isolated port to the transition and inject DC bias voltage or extract some lower frequency signal from the active component on the substrate. Shi and Inatani proposed a similar device [1] for a half-height waveguide. The transition used a probe crossing the entire waveguide height and directly connected to an RF filter choke. In contrast, we propose a design suitable for a full-height waveguide, therefore with reduced RF losses and more easily machined, important advantages that become especially critical for mm and sub-mm frequency waveguide components with extremely small dimensions and high losses. Authors intend this work as application of this technology in sub-mm wavelength: the entire mixer structure to be fabricated in one technological process together with the active component, a superconducting tunnel junction mixer [2], [3].

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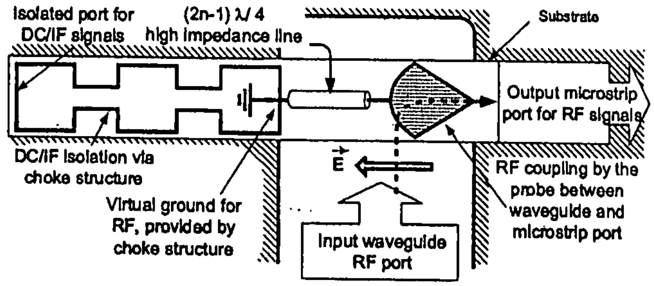

Fig. 1. Block diagram of the proposed structure. The high impedance line of $(2n-1)\lambda/4$ is short-circuited at the plane of the waveguide wall (to the left) by the choke filter.

II. Probe Design

Waveguide-to-microstrip transitions are a popular component of microwave and mm-wave technology and have been widely studied by many authors [4]–[6]. Usually the probe is fabricated using planar technology; metal film is deposited on a dielectric substrate providing mechanical support. The substrate is placed parallel to the E field in the waveguide. The probe is shaped in order to achieve desirable performance, broadband or frequency selective matching between the waveguide and the probe output, typically a microstrip line.

We selected a radial type probe allowing a broadband matching and wide range of attainable output impedance [7]. With the aim of adding an isolated port for DC and IF signals, we connect the probe wide side (Fig. 1) via a conducting line to the other side of the substrate near the waveguide wall.

In order to avoid influence of the isolated port on the performance of the waveguide-to-microstrip transition, we use a high impedance transmission line with a length corresponding to an odd number of quarter wavelengths that connects the probe to the isolated port. At the waveguide wall plane, the line end, a choke structure is introduced, providing RF ground (floating) for the high impedance line and port for DC and IF signals. The detailed design of the suggested structure is shown in Fig. 2. The input waveguide (1) is coupled to a microstrip line (2) and both are isolated from the DC-IF port (3). The substrate (4) made of crystal quartz is placed in the substrate channel with subcritical dimensions to prevent propagation of unwanted waveguide

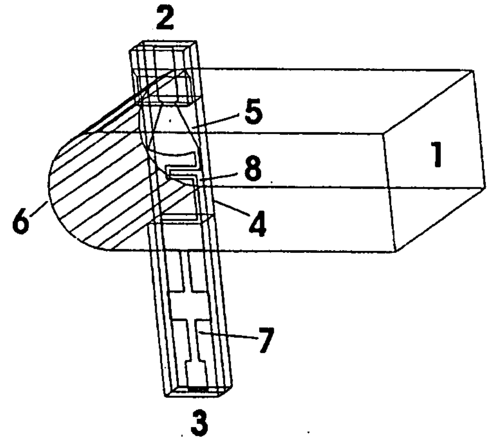

Fig. 2. Layout of the proposed waveguide-to-microstrip transition with integrated bias-T: 1 – waveguide input port, 2 – microstrip output port, 3 – isolated microstrip DC-IF output port, 4 – quartz substrate, 5 – radial probe, 6 – waveguide cylindrical backshort, 7 – RF choke, and 8 – high impedance line with adjusted electrical length.

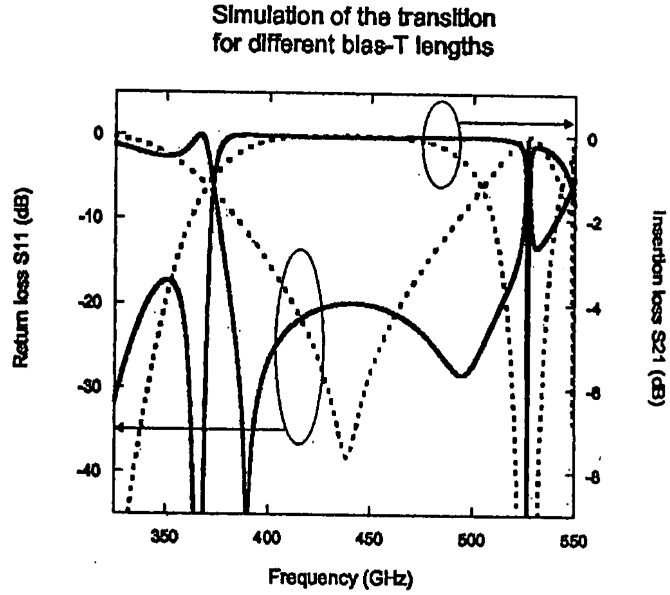

Fig. 3. Simulation of a transition for 375–500 GHz. The dashed curves are for high impedance line length of about $\lambda/4$ (150 μm), and continuous lines are for a length of about 3 $\lambda/4$ (300 μm). The top curves are the insertion loss S21 between the input waveguide and the output microstrip line and the bottom curves are return loss S11. Bandwidth is 30% of the center frequency.

modes. The substrate is positioned along the direction of propagation in the middle of the waveguide broad wall, to allow the use of a split-block technique for manufacturing of the transition. However the substrate can be rotated 90° along its axis without noticeable changes in the performance, as shown in [6].

The RF probe is of radial type with its radius extending to 40% of the waveguide height. The center of the microstrip is located at approximately $\lambda/4$ from the waveguide fixed backshort (6), which has cylindrical profile to facilitate manufacturing for high frequency transitions (above 100 GHz), when dimensions become miniature. We employ a microstrip RF choke (7) in the DC/IF port with the purpose of providing a virtual ground in the plane of the waveguide wall to isolate this port at RF. In order to achieve DC/IF connection we attach the choke to the radial probe via a high impedance line (8).

Interestingly, the length of the high impedance line and its shape as well affect the performance of the proposed device. For a substrate suspended in a waveguide, the impedance and effective dielectric constant of a longitudinal transmission line (parallel to the substrate long side) are much lower than those of transverse lines [8]. Therefore, in order to obtain the highest impedance for this line we need a longer overall length and allow substantial extent in the transverse direction. High order evanescent modes are excited by the discontinuity introduced in the waveguide (substrate and metallization) and store reactive energy. A large part of the probe reactance is tuned out by the waveguide backshort but also by the high impedance line.

We designed a 375–500 GHz transition for applications in sub-mm low-noise receiver. Different lengths for the high impedance line were simulated with HFSS [9]. Results for a $\lambda/4$ and $3\lambda/4$ are shown in Fig. 3. The waveguide dimensions are 540×270 μm; the substrate (crystal quartz) with dimensions 50×130 μm. The high impedance line of 300 μm long with the loop structure in the middle section, which was created to gain the length for the given limited space, was found to give the best results. Bandwidth of the probe, limited by the resonances of the high impedance line, corresponds to 30% of the center frequency where return loss is better than -20 dB.

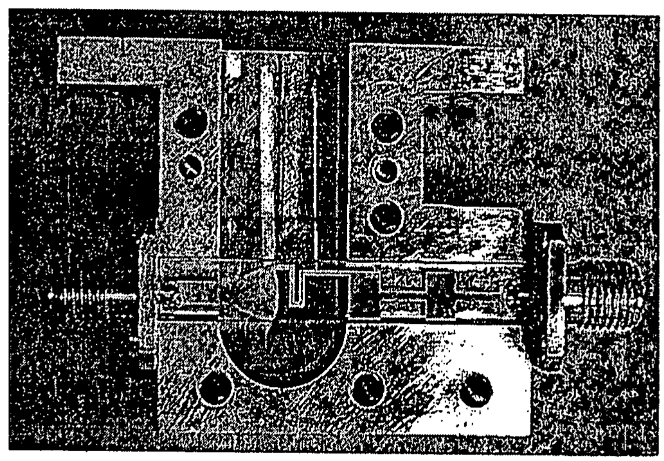

Fig. 4. Photograph of the split part of the X-band transition. Split-block techniques is used, cylindrical backshort is done to facilitate fabrication at high frequencies.

If the proposed structure is used for a waveguide mixer with a mixer diode placed around the origin of the radial probe, the total length of the transmission lines on the substrate, with its corresponding inductance is small enough to allow not only DC bias but IF signal to be extracted with this bias-T. Modeled insertion loss is lower than -0.1 dB for frequencies up to 2% of the center RF frequency.

III. Measurement on X-Band Transition

An X-band transition was constructed (Fig. 4) and extensively tested in order to confirm the modeling. The center frequency was chosen at 11 GHz. The waveguide dimensions are 22.86 by 11.43 mm^2. The substrate is made of crystal quartz

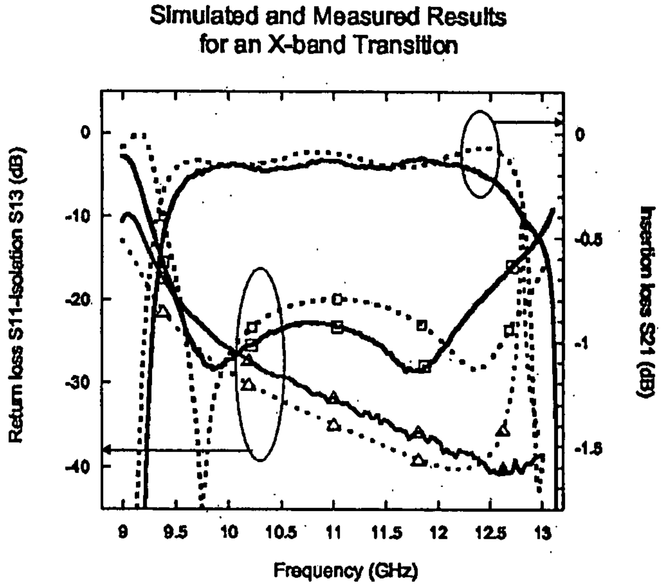

Fig. 5. Continuous lines are for measured results and dashed lines for simulated results. Center frequency is 11 GHz. Upper curves are insertion loss, middle curves with squares are return loss and lower curves with triangles are isolation between waveguide RF port and DC-IF port.

with 1.7 mm height, 5.5 mm width and 33 mm length. The microstrip output lines are designed having 50 Ω characteristic impedance to easily match 50 Ω SMA connectors. The entire structure is proportionally scaled from the one simulated in the previous section. The high impedance line is about 13 mm long and 0.4 mm wide.

The results of the measurements compared with the simulated performance are presented in Fig. 5. The measured insertion loss is about -0.15 dB across the band 9.5 – 12.5 GHz and includes losses from the SMA connector, conducting losses and dielectric loss in the quartz substrate. The return loss is better than -20 dB, and the isolation between RF ports and the DC-IF port is better than -20 dB. Agreement with the HFSS simulation is excellent. The RF bandwidth achieved is 30% of the center RF frequency.

Measurements between the two SMA connectors (RF output and the isolated port) confirm that signals from DC up to 200 MHz (2% of the center RF frequency) can be extracted via the bias-T port with an insertion loss less than -0.1 dB.

IV. Conclusion

A waveguide-to-microstrip transition with an integrated wide band bias-T was designed, built and characterized using X-band scale model. The suggested structure allows injecting DC currents and extracting IF signals without affecting the performance of the RF part of the transition. RF bandwidth is 30% of center frequency with return loss better than -20 dB. The insertion loss between the RF ports is about -0.15 dB, and the isolation for the bias-T port is better than -20 dB. The proposed device provides an elegant way of biasing active devices such as pin diodes, hybrid waveguide-microstrip transistor amplifiers and mixers. The built-in isolated port allows also extraction of intermediate frequency signal up to 2% of the RF frequency if used with a mixer diode.

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